Tevatron Performance and Plans

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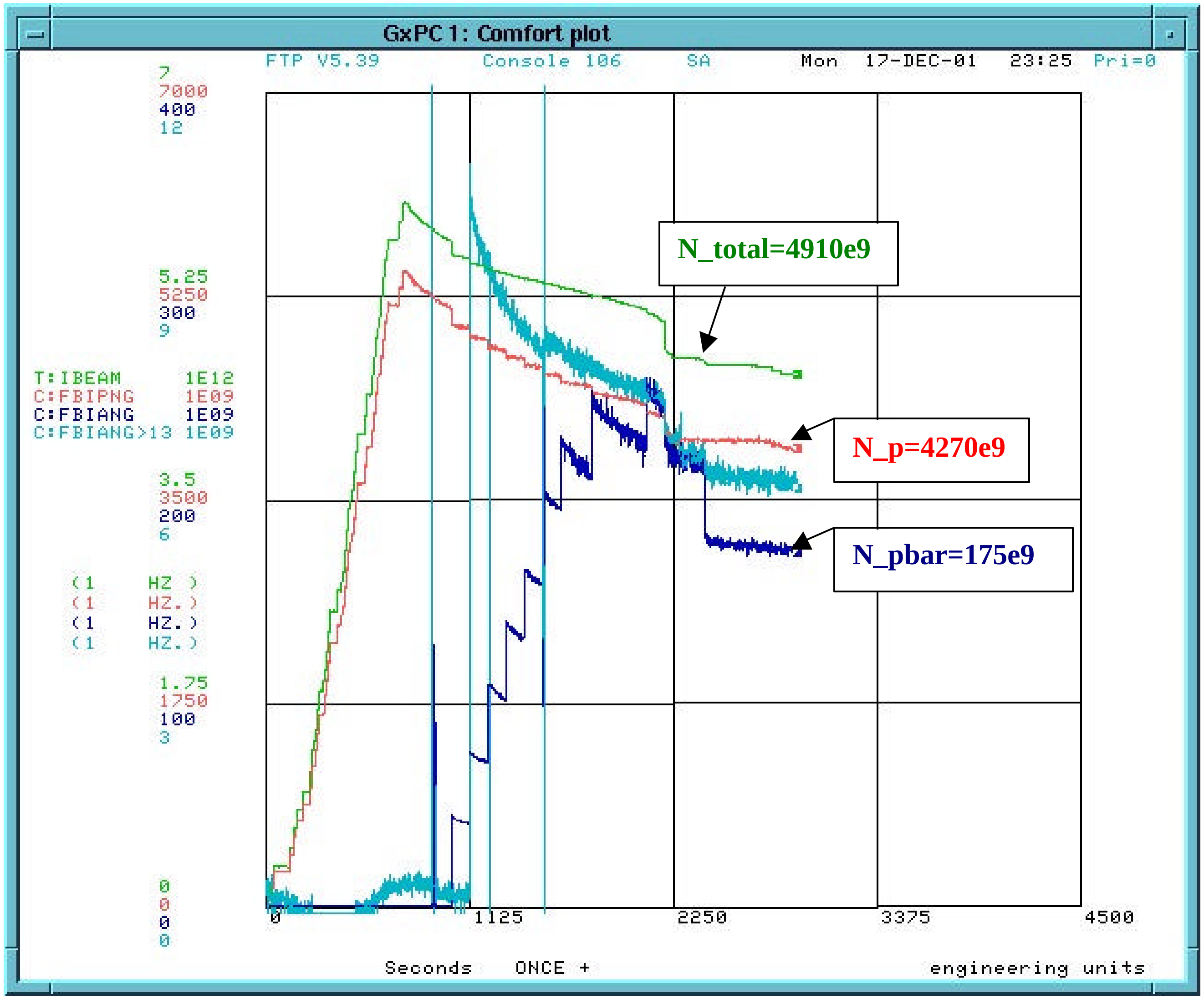
1. Collider Improvements: Luminosity
   "Battle for Pbars"
   Proton Issues

2. Plan for studies

3. Plan for shutdowns 2 week shutdown
   5 week shutdown

…6 months ago: store 843, Dec 17, 2001



N_pbar=5e9/bunch, N_p=120e9/bunch, CDF Luminosity 7.5e30, emittances ~17 π mm mrad in both beams (estimate!)

Major luminosity loss drivers in the Tevatron:

Pbar loss at transition from injection to collision helix ("Sequence 13 loss")

was	15% → 25% (in Feb-March)
now	about 3-5%

Pbar loss at the ramp

was	10% → 22% (in April)
now	10-15% (for higher p-intensity)

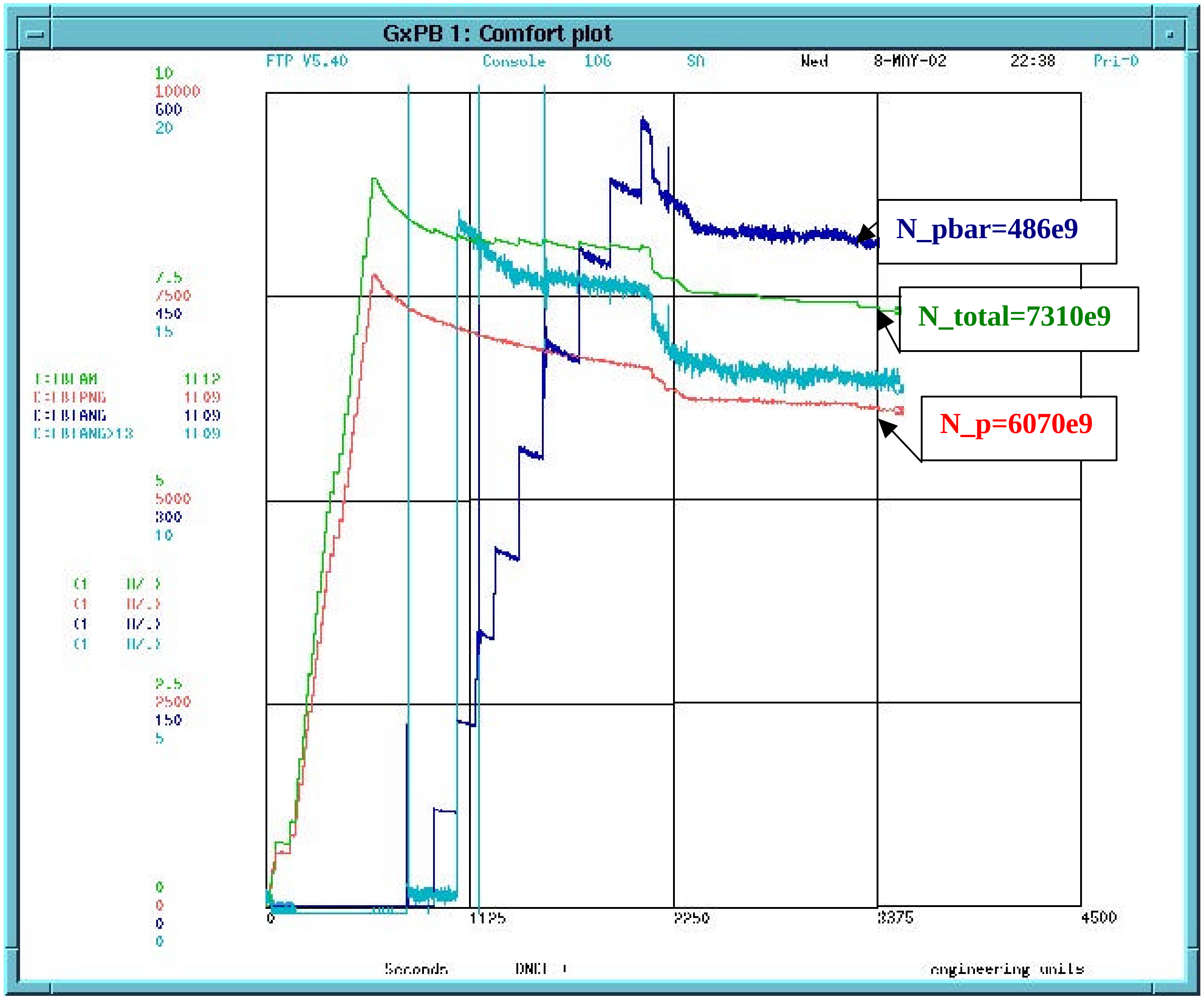
Pbar loss due to poor lifetime at injection energy 150 GeV

was	upto 25-30%
now	about 20-25% (for higher p-intensity)

Proton loss due to poor lifetime at injection energy 150 GeV

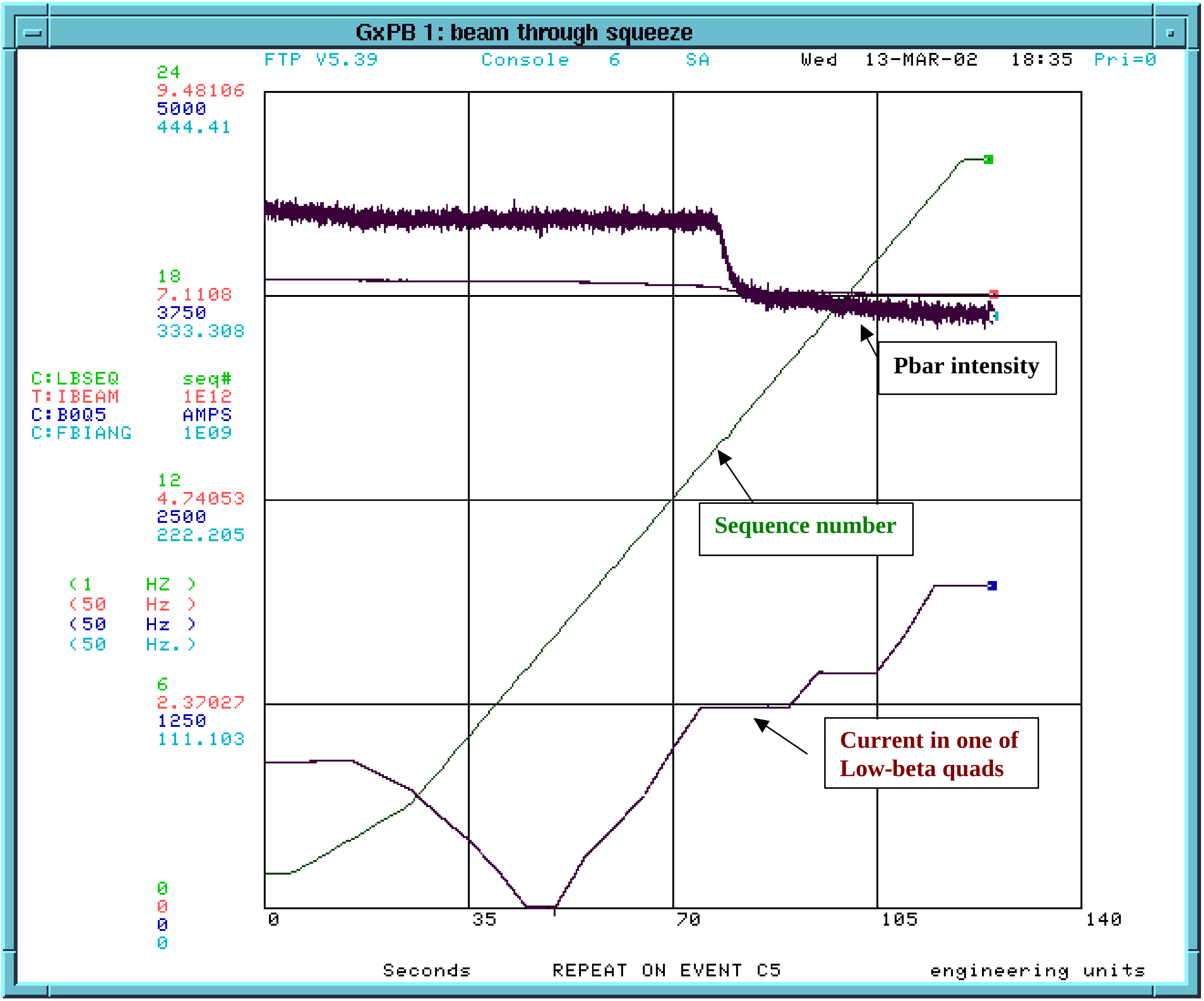
was	upto 25-35%
now	10-15%

…recent (not record *L*) store 1303, May 8, 2002



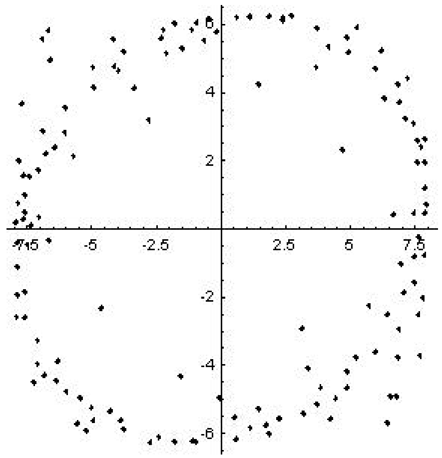
N_pbar=13.5e9/bunch, N_p=170e9/bunch, CDF Luminosity 20.4e30, emittances ~25 π mm mrad (measured!)

“Sequence 13” = long-range beam-beam effect:

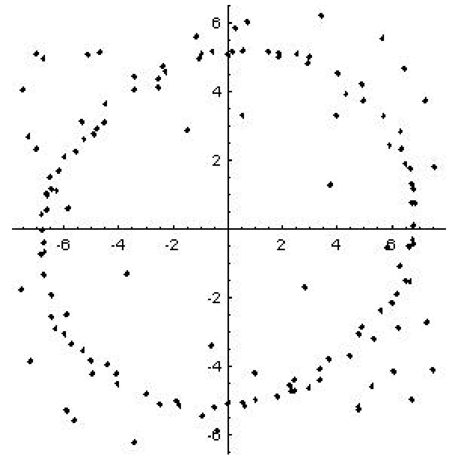


Minimum separation turned out to be only **1.8**s!

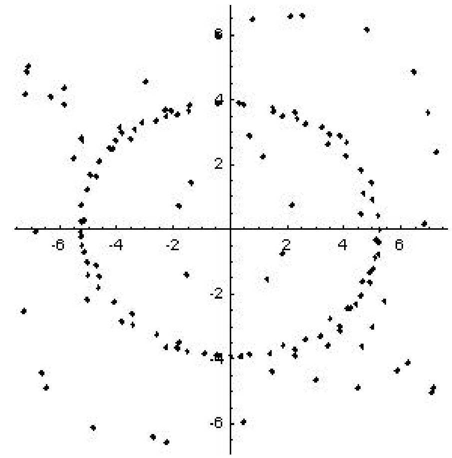
Normalized separations $\Delta x/\sigma_x$, $\Delta y/\sigma_y$ at all possible IPs with 36×36 collision cogging in sigmas for the reference emittance ε_n=15π mm·mrad. t = 0 – seq13, t = 1 – seq14.



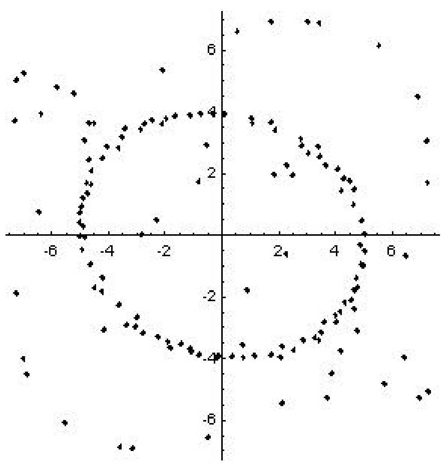
t = 0



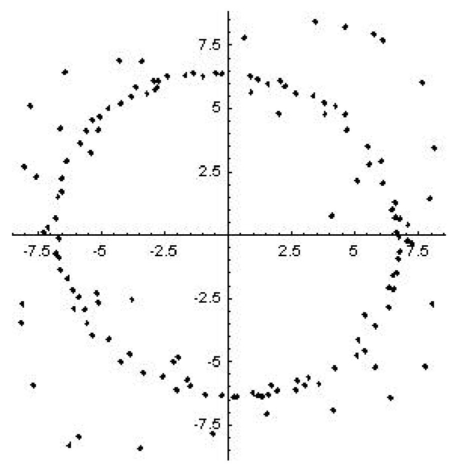
t = 0.1



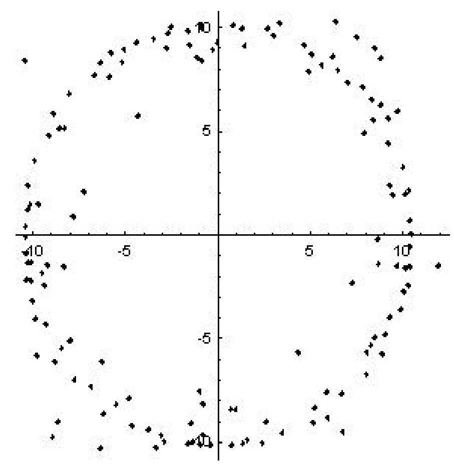
t = 0.3



t = 0.4

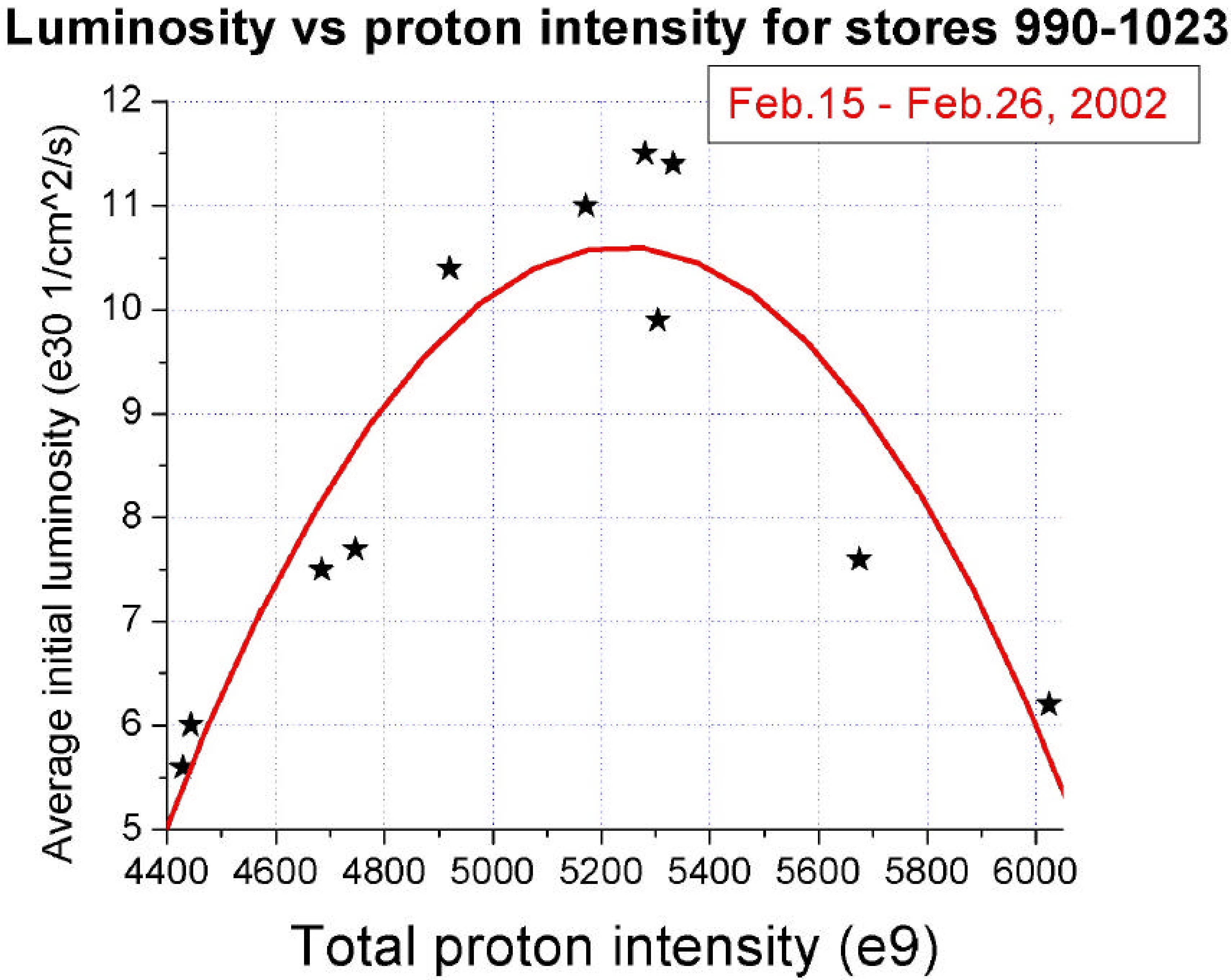


t = 0.7

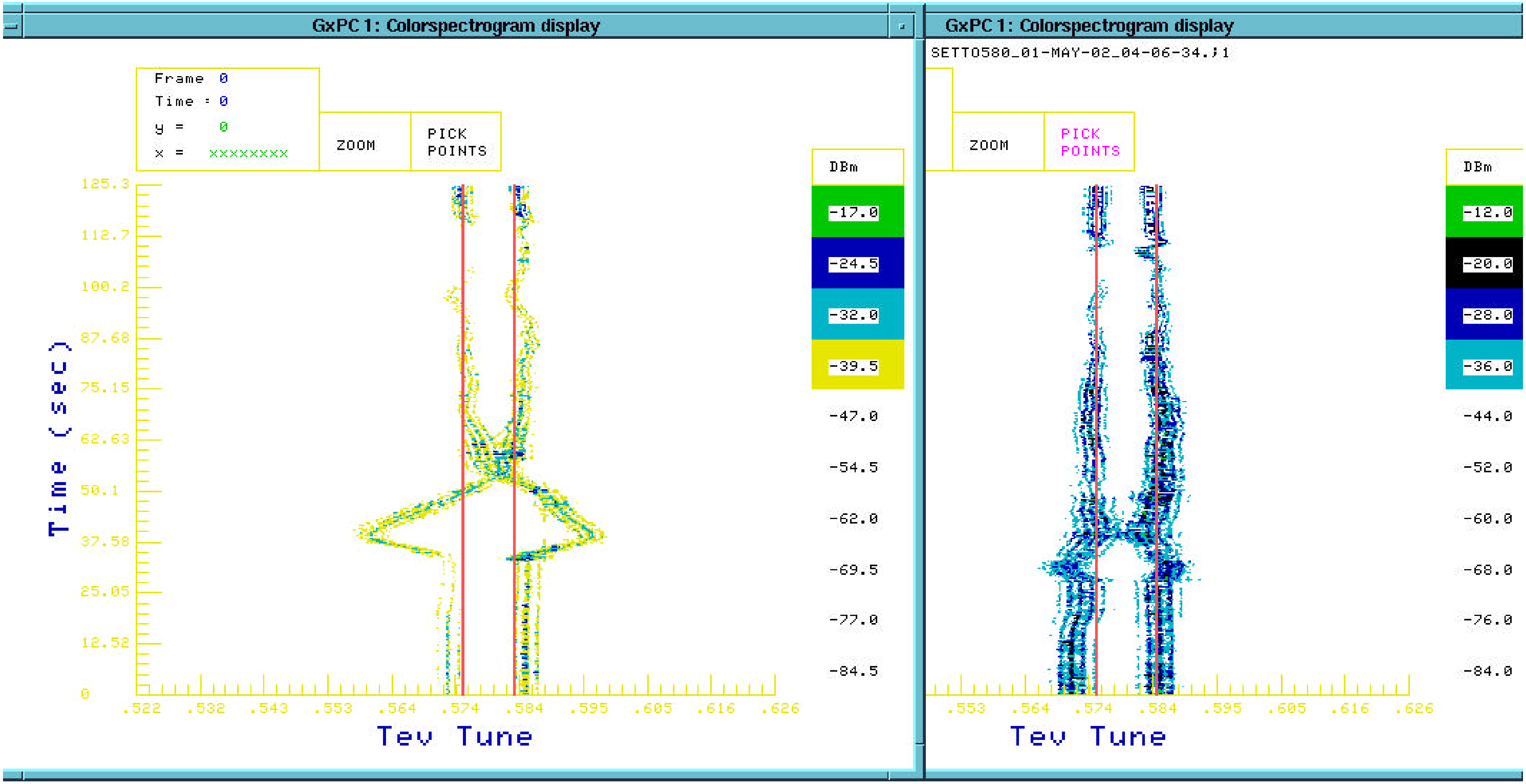


t = 1

The separation has been increased to **2.7**s **and the loss gone**

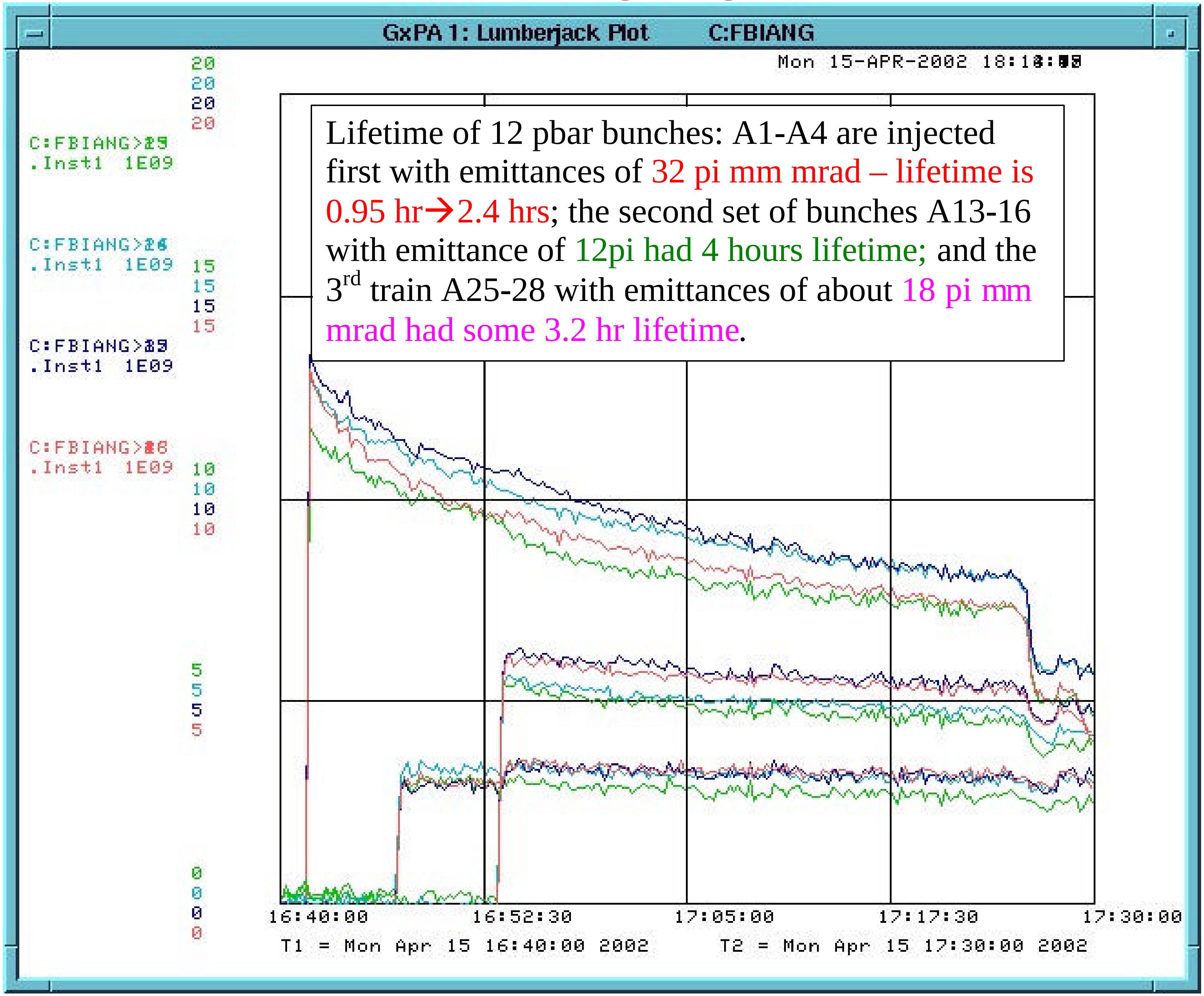

Luminosity vs proton intensity for stores 990-1023
Feb.15 - Feb.26, 2002
Average initial luminosity (e30 1/cm^2/s)
12
11
10
9
8
7
6
5
4400
4600
4800
5000
5200
5400
5600
5800
6000
Total proton intensity (e9)

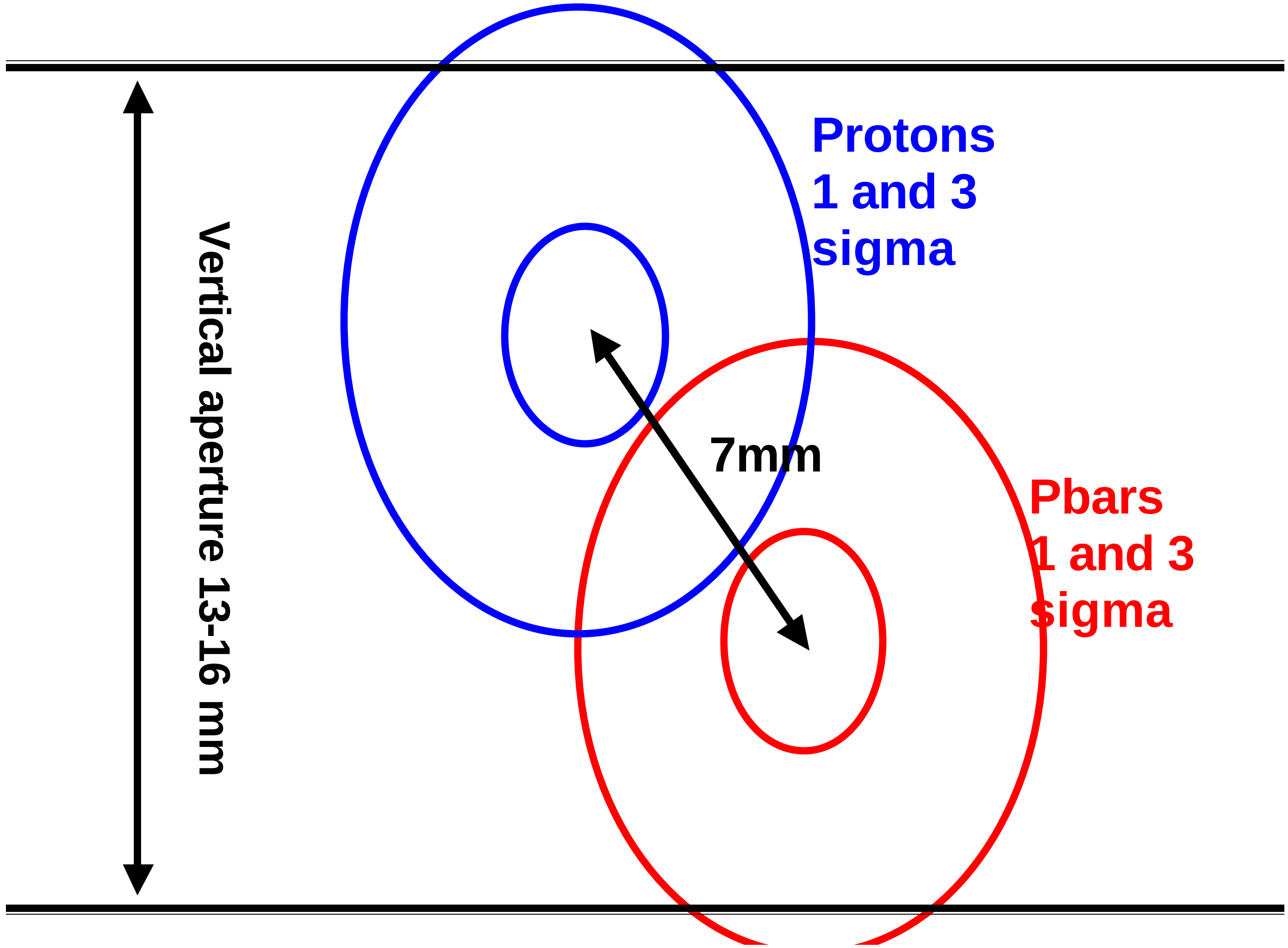
Pbar loss at the ramp = long-range beam-beam effect:



The loss depends on proton intensity, beam-beam separation (has been maximaized with given restrictions), tunes, coupling, chromaticities (variations were corrected with additional break point at 153 GeV – see Fig. – tunes vs time: before and after)

Pbar loss at 150 GeV = long-range beam-beam effect





Schematic presentation of 150 GeV issues: pbars are too close to protons (~4σ) which work as "soft collimator", but physical aperture at C0 Lamberson is close too. Solutions: increase separation by tilting helix, increase aperture, reduce sigma, faster injection. We are doing all that. So far the first approach was tried.

General comments on beam-beam effects in the Tevatron:

3 problems are serious: pbar losses at 150 GeV, at the ramp and during squeeze – all of them are long-range beam-beam effects. Head-on beam-beam interaction is not an issue (yet?).

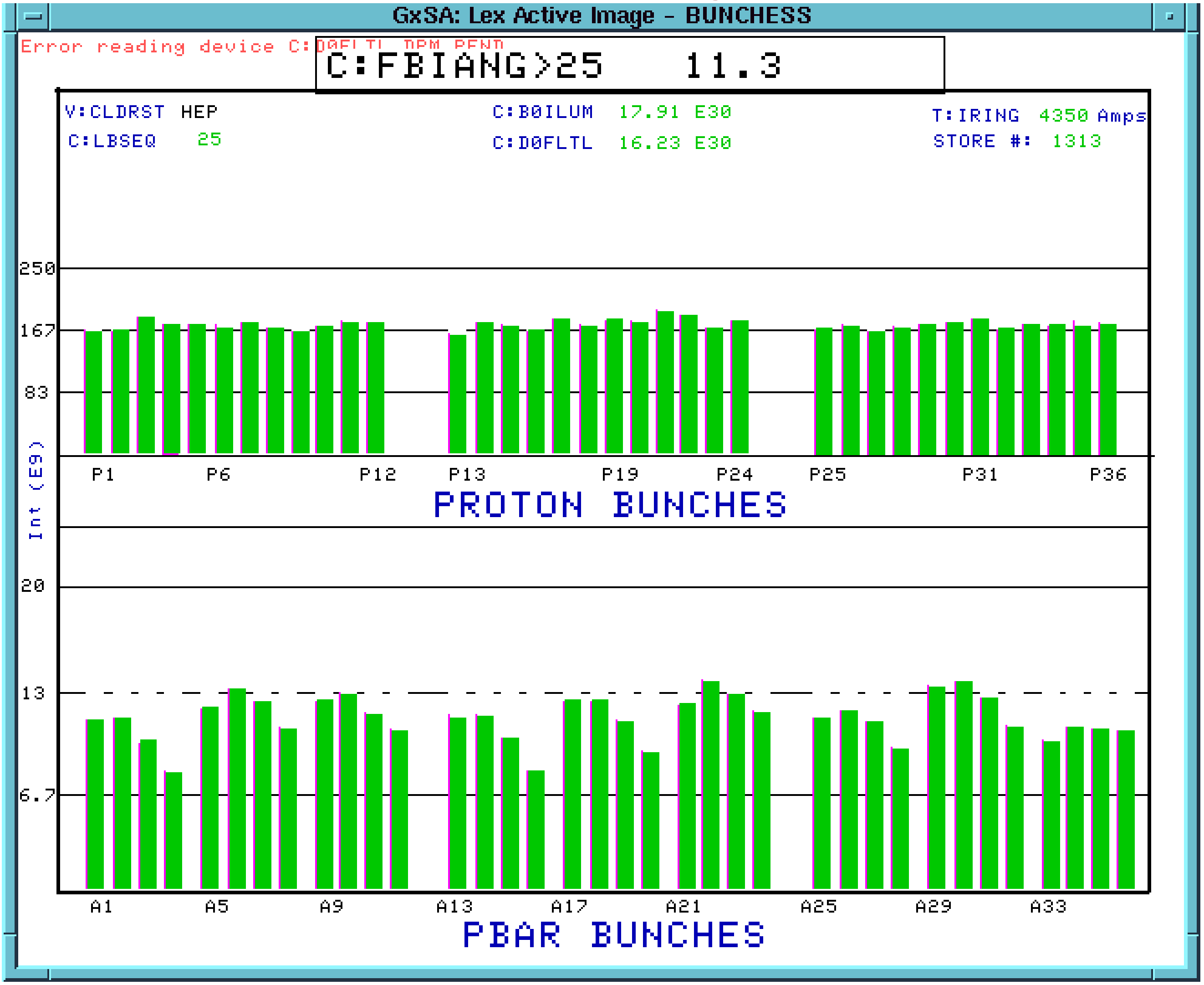
The losses depend on: proton intensities, minimal beam-beam separation around the ring, pbar emittance, lifetime is worse if tunes move close to resonances (e.g., 3/5, 4/7), beam aperture is limited and orbits move.

Losses vary bunch-to-bunch see intensities early in store 1313

Long-range beam-beam effects (less seriously) manifest themselves at 980 GeV see bunch-to-bunch lifetime variation.

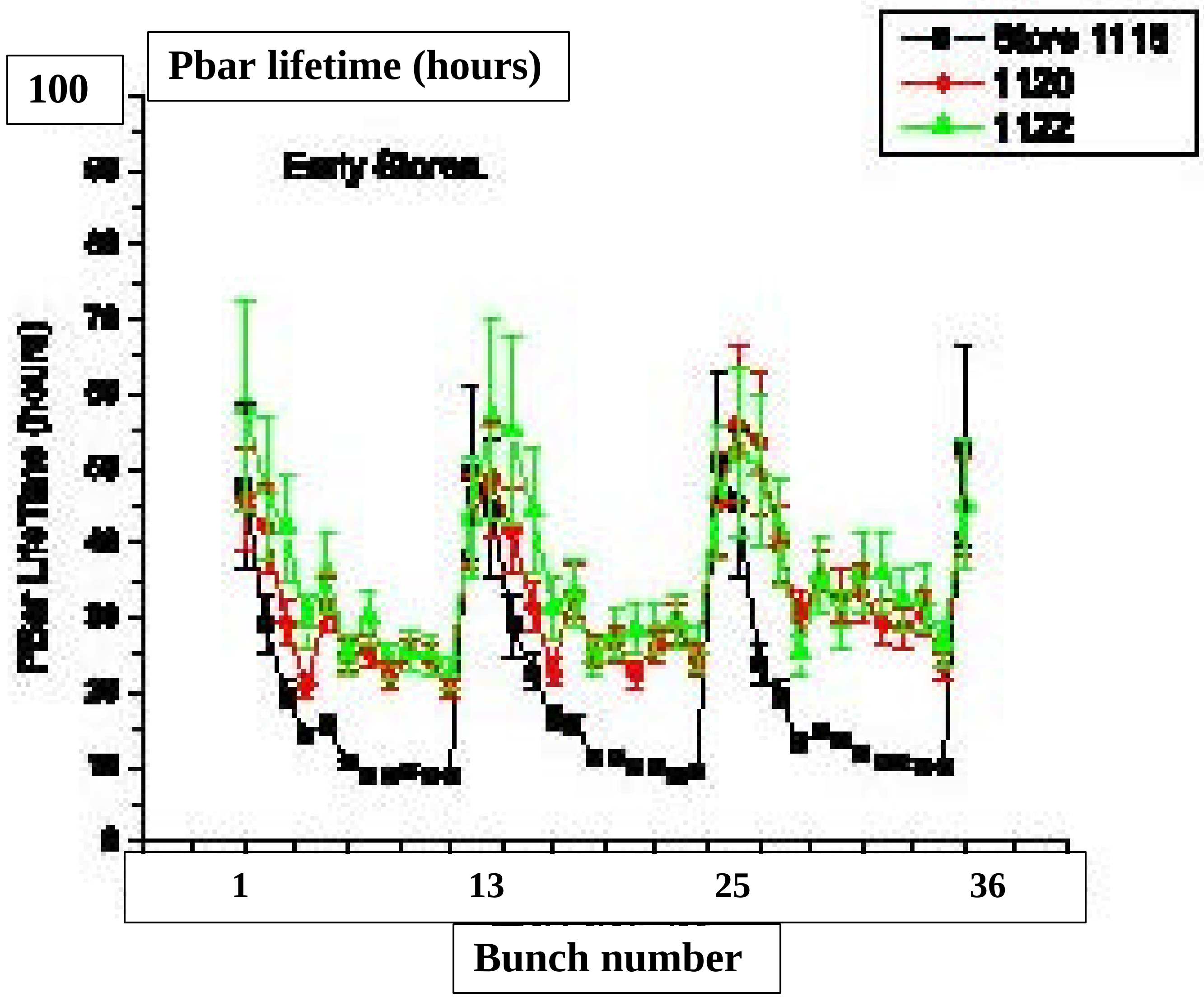
We need more maturity in our beam-beam models.

Beam intensities early in store 1313



Some 7% variation in protons and 35% in antiprotons – the latter due to losses at 150 GeV, ramp and squeeze (pbar intensity variation at injection is about 15%)

Antiproton lifetime at 980 GeV depends on bunch position



Proton Issues in the Tevatron:

1. Poor lifetime at 150 Gev (2-4 hours) leads to some 15% of the beam loss.

2. CDF background : vacuum?

3. DC beam

4. Longitudinal instabilities: at 980 GeV (bunch length blowup) and 150 GeV ("dancing bunches")

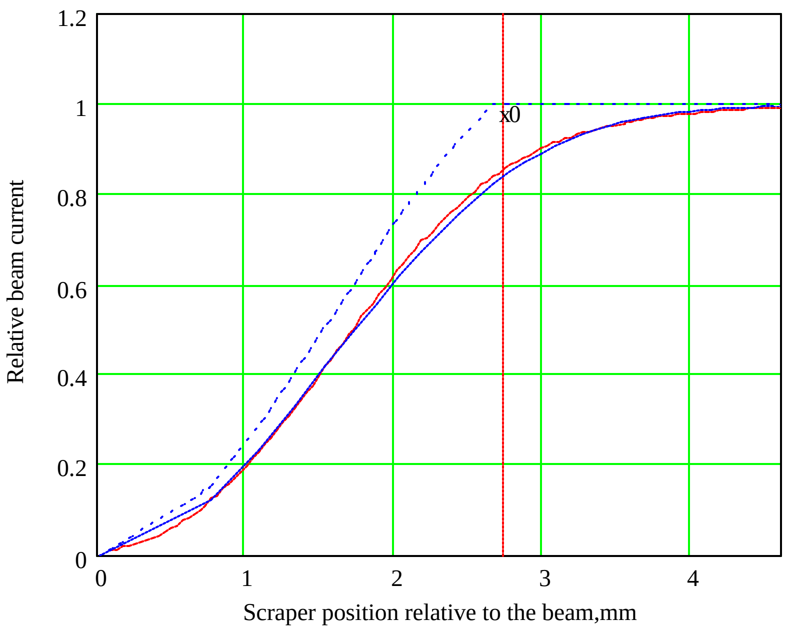
5. Transverse instabilities: 150 GeV and 980 GeV (beam "goes coherent")

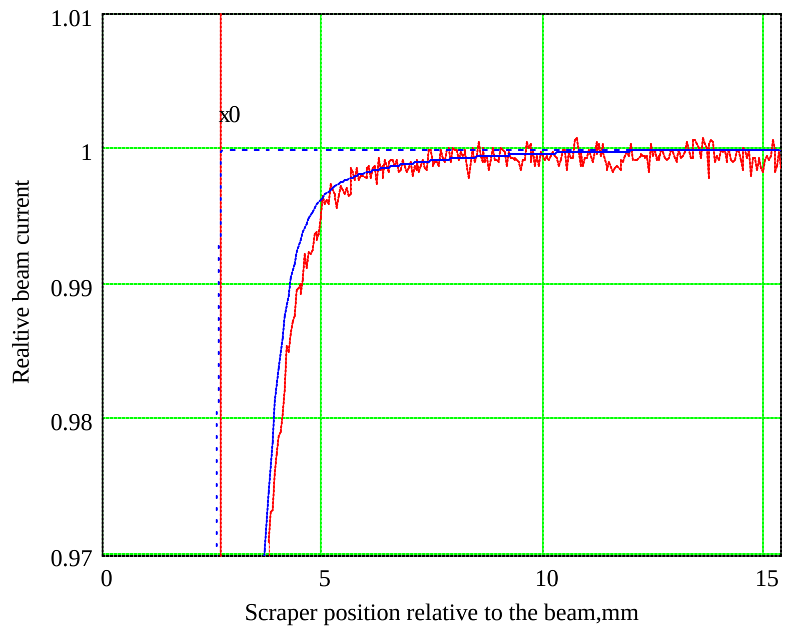
So far, only **item 1** does affect the luminosity directly, but there are tight connections between all the items (e.g., 4,5→1, 3,4→2, and even 2→1)

1. Poor lifetime at 150 Gev :

Currently we believe there are three mechanisms for that:

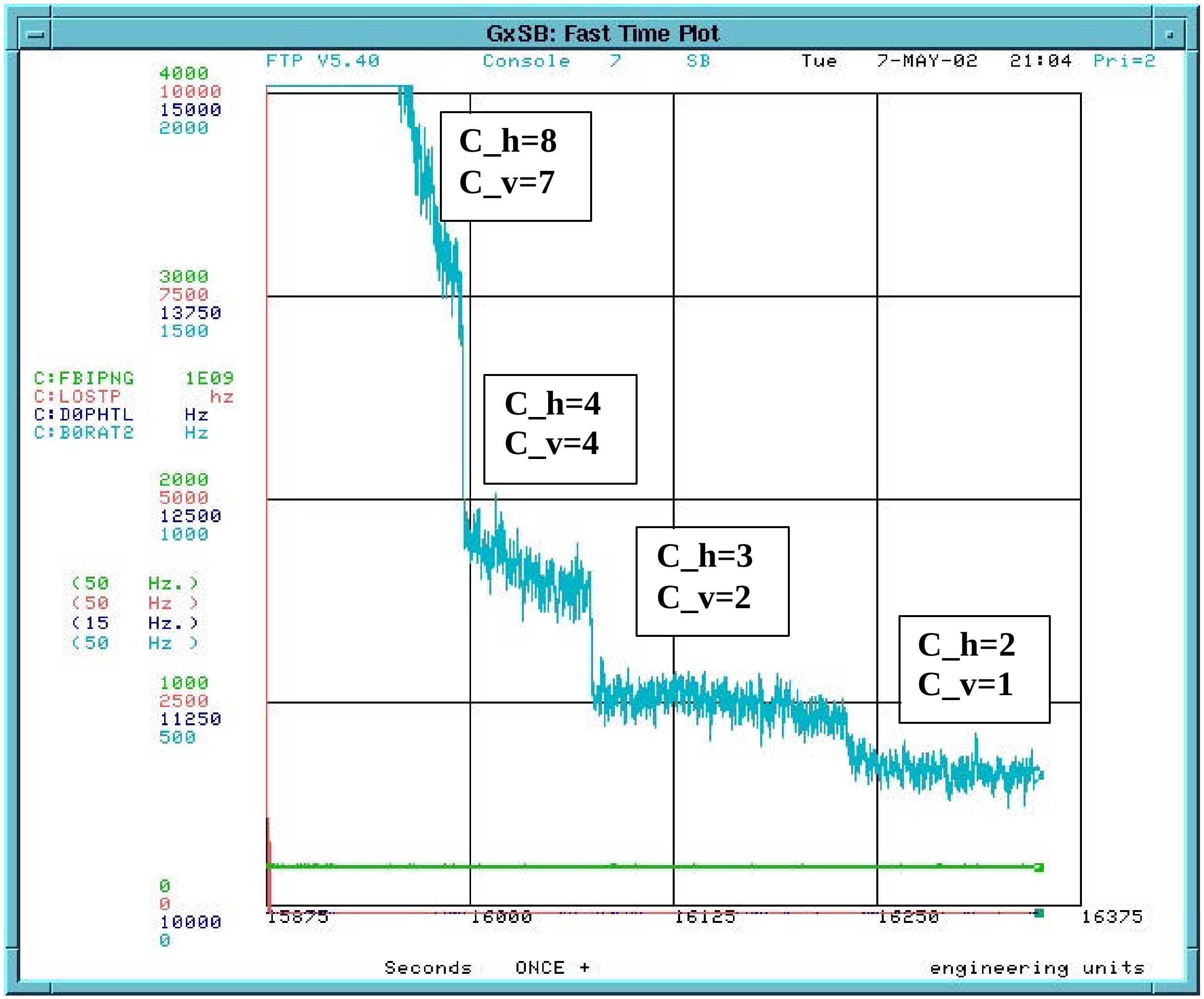
a) Transverse emittance growth due to gas scattering in presence of tight physical aperture restrictions:





Dependence of the beam current on scraper positions after scraping the beam to 12 mm mrad and 1 hour beam expansion. Blue line - theory prediction if both multiple and single scattering are taken into account; red –lines measurement results. Right side presents the same data but with better resolution of tails. From these results we get some 5 π mm mrad/hr growth rate and 4e-9 average Tev vacuum (N_2 equivalent) .

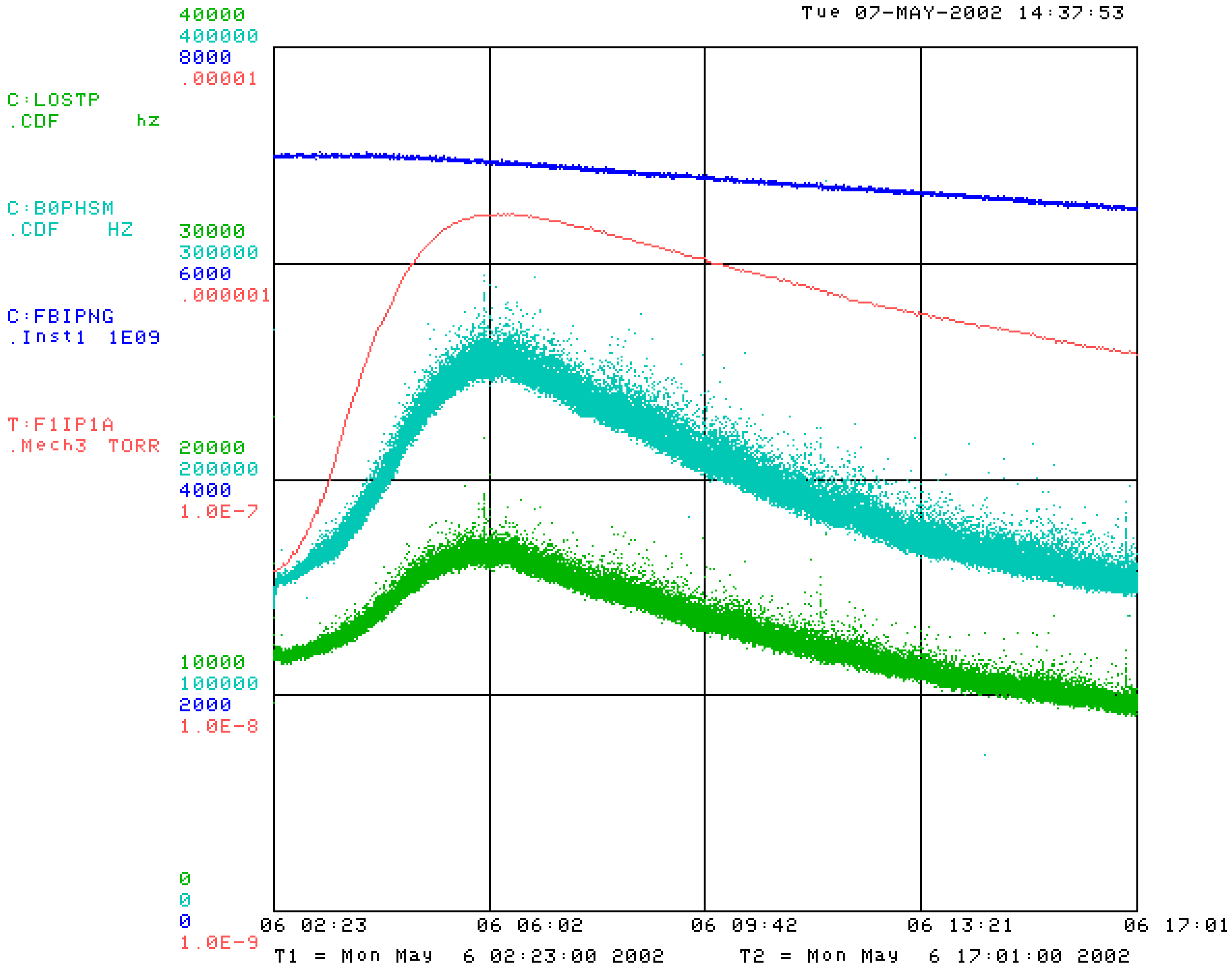
b) Large dQ due to chromaticity in limited good working point space (tune aperture):



Blue line – p-loss rate (dN/dt) – which goes down for smaller chromaticities *C*. For 36 p-bunches the only way to keep around C=4 is to introduce tunespread by octupoles, otherwise beam is unstable (weak head-tail → abort on losses).

c) Leakage out of RF bucket: DC beam lifetime is somewhat better than bunched beam lifetime (longitudinal emittance aperture).

2. Detector background issues:

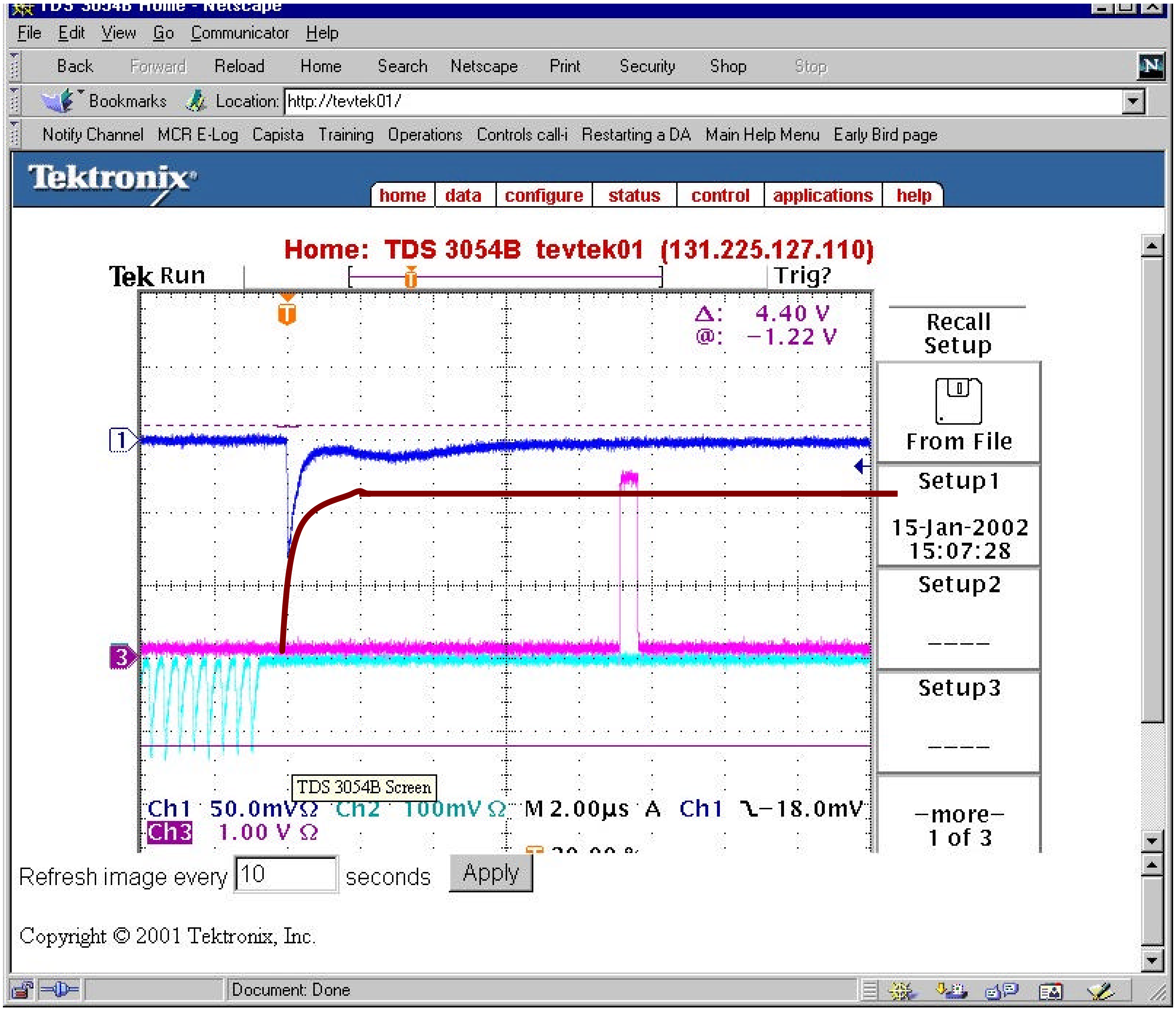


a) average level is high – sometimes “unacceptable” for the CDF
b) optimization of collimator positions resulted only in 20% background reduction
c) “bump” – see CDF losses above – due to F11 vacuum (2e-6 Torr over 2.6 m, while Tev average is 2e-9 Torr)

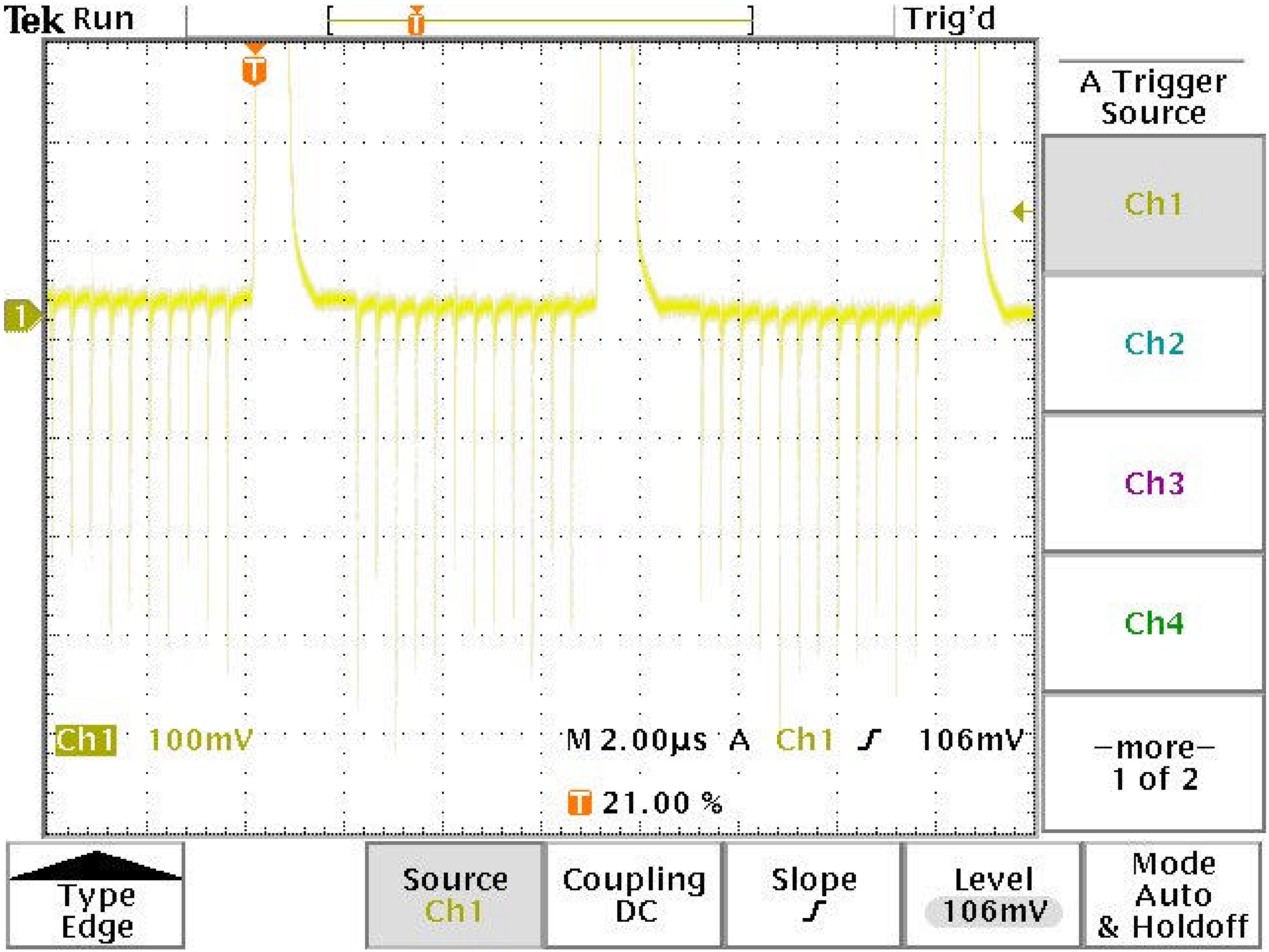
3. DC Beam and quenches on abort, Tevatron Electron Lens as abort gap cleaner and coasting beam removal tool

Problem: starting about Dec 21, 2001 we quenched CDF low-beta quads on almost every beam abort (total ~30 until fixed)
Reason: DC beam in the abort gap, >6x10^9 or ~0.1% of N_{total}
Solution: TEL was used as a DC beam cleaner:

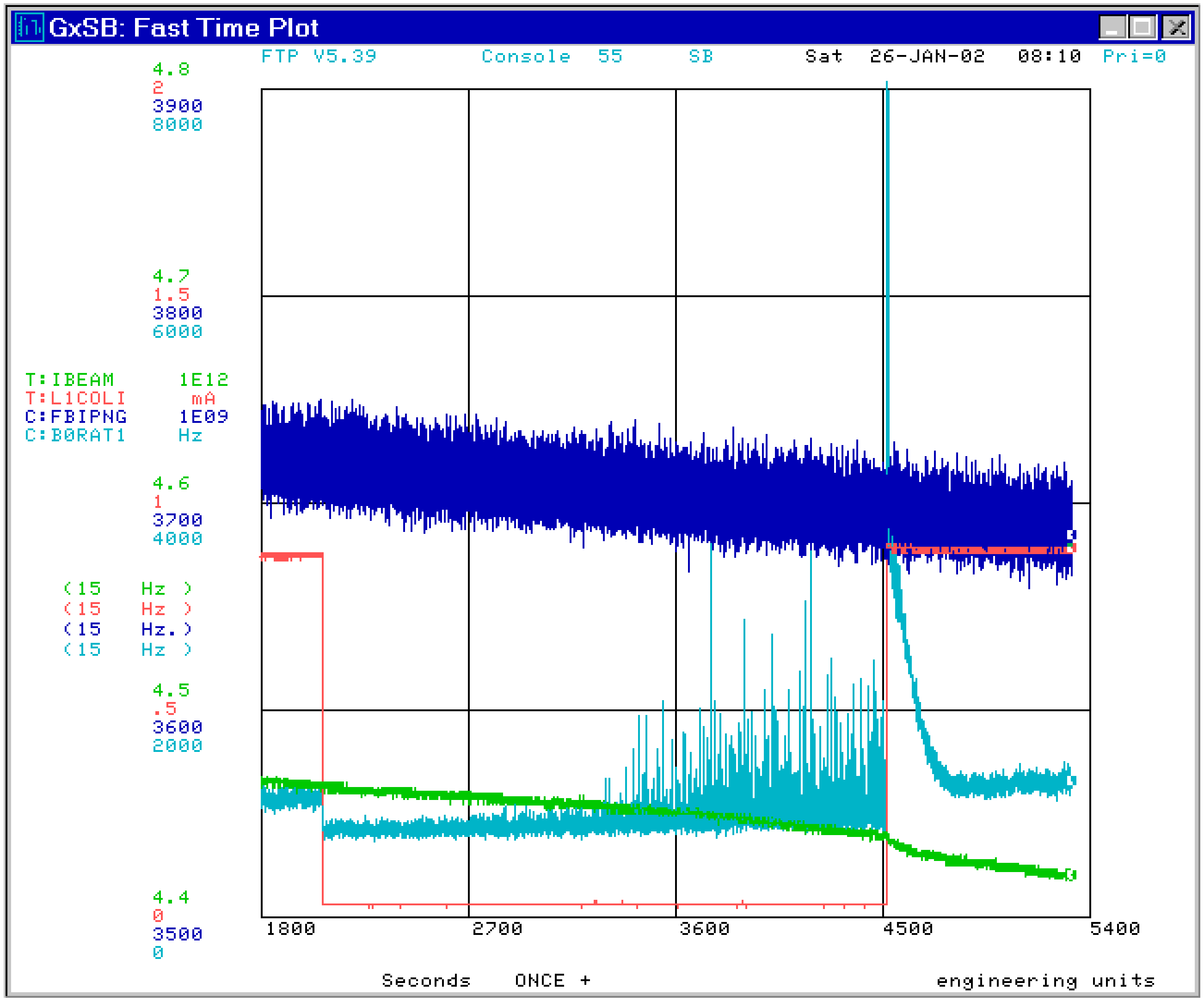
- e-beam SC force drives 7^{th} order resonance → losses
- TEL is equivalent to 1MW "tickler" (vs 50W in Q-mtr)
- e-current is fired every 7^{th} turn only in 3 Tevatron gaps
- e-beam placed to edge the p-orbit helix
- TEL reduces DC beam intensity and eliminates spikes in the CDF losses
- currently TEL is operational: now it is turned ON early into each store, then OFF for ½ hour at the end of each store and then ON again to see the DC beam
- though the leakage out of RF bucket (due to RF noise-?) is 50% less than in Dec'01, the cleaning is still needed



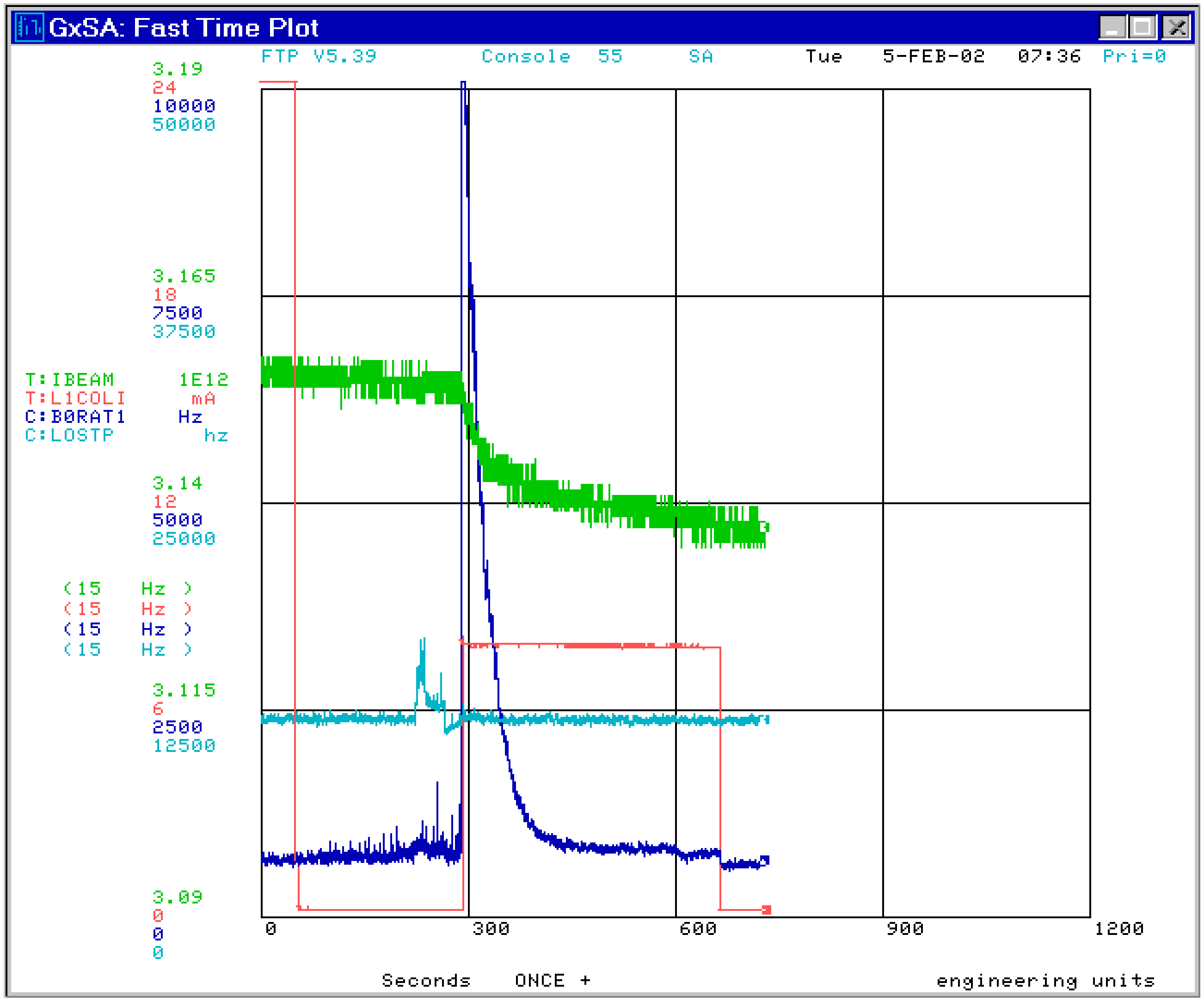
Cyan- bunches, Blue – BBU1 scintillator, Brown – abort kick



TEL pulses cover some 1 microsec in abort gaps. J_peak≈0.5A.

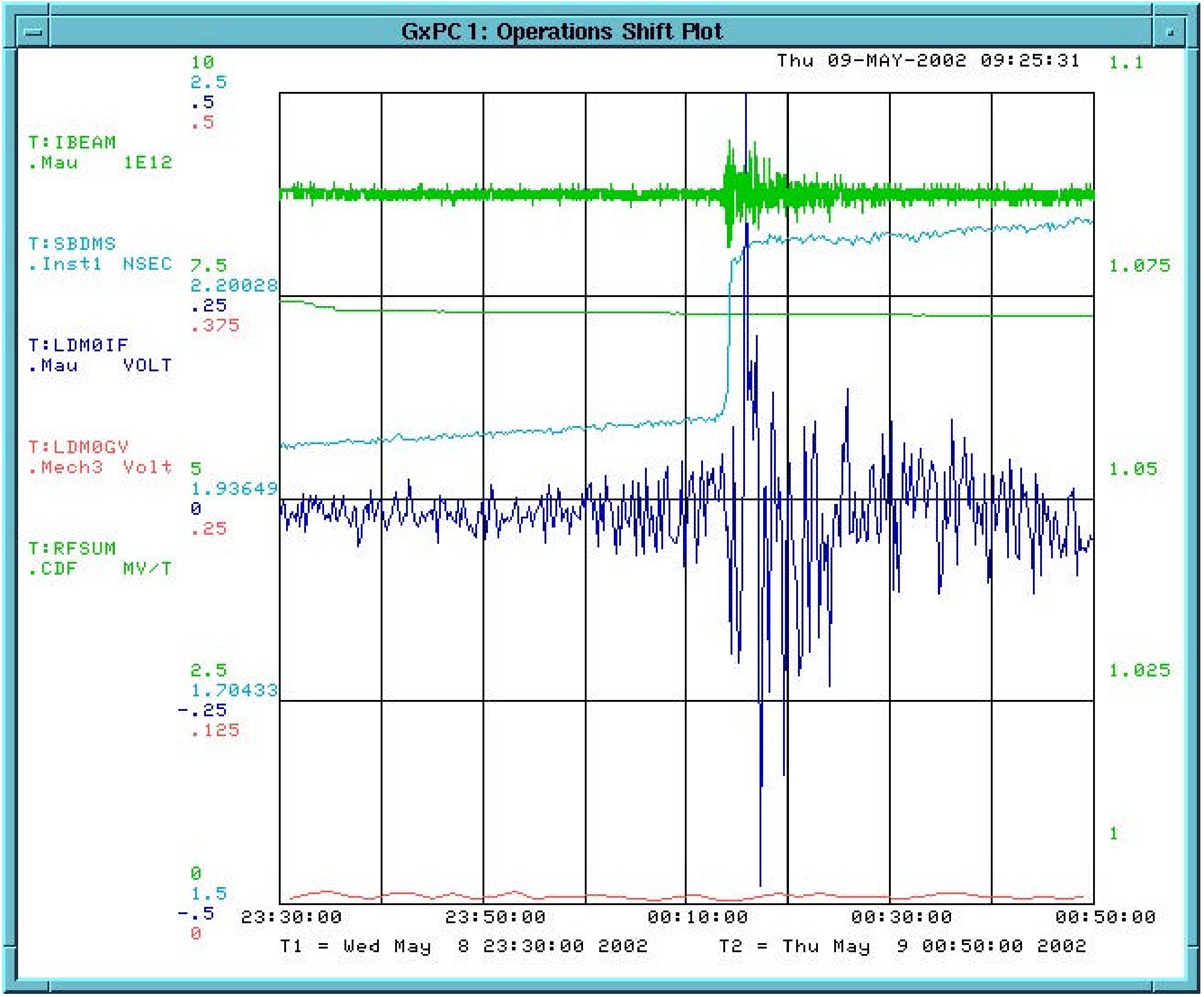


Without the TEL, DC beam accumulates in 10-15 minutes and spikes appear in the CDF background.



TEL kills a good portion of the DC beam in about 90 seconds (see above – optimized position and 1 A current). Kink in IBEAM corresponds to the DC beam intensity drop of 1.8e9 protons.

4. Longitudinal emittance growth and blow-ups



a) initial emittance is large (~ ½ RF bucket area at flat top)

b) σ_s=2 + (0.03-0.1)ns/hr – growth consistent with known RF noises (some 60 urad in RF phase or/and 70V in voltage), "microphonics" idea

c) longitudinal feedback does not help much yet (due to own noises)
d) frequent σ_s blowups (every other store) / RF failures rare (Mar.30)
e) bunch length growth and blowups result in very little luminosity drop but significant detector background increase and DC beam.
f) at 150 GeV "we see dancing" bunches (in both uncoalesced and coalesced beams). Effect seems to be more prominent at higher proton bunch intensity and does bother us because RF bucket is already full at injection.
g) we are improving our longitudinal dampers

5. Transverse beam dynamics:

a) "weak" transverse instability at 150 GeV, aperture limits blowup
b) at 980 GeV we occasionally observe beam going coherent in vertical plane slowly, without loss of the current (but background rises), it may stay for hours, slowly disappears after either coupling tune-up or increase of chromaticity; the phenomena not studied well
c) transverse emittance growth rates are about 0.3-0.6 πmm mrad/hr in both vertical and horizontal planes, in both p and pbar beams – above the Run I rate of 0.2-0.4 πmm mrad/hr.

2. Plan of studies: [Potential *L* increase – do not add!]

- pbar lifetime to be improved by better separation [20-30%]
- proton intensity increased by coalescing more bunches in MI and TEL-cleaning DC beam in the TeV at 150 GeV [20-30%]
- octupoles or transverse damper allow to reduce chromaticity at 150 GeV and improve proton lifetime [10-20%]
- Tevatron parameter drifts at 150 /ramp [10-15%]
- faster pbar injection [10 %]
- pbar loss at the ramp decreased by better separation [5-10%]
- injection dampers: longitudinal and transverse [5-10%]
- MI→TeV transfer tune up to increase number of pbars [5%]
- collimator studies
- 980 GeV longitudinal and transverse emittance studies (noise vs vacuum vs nonlinearities)
- proton instability studies at 150 GeV and at 980 GeV
- diagnostics test/improvements (BPM, SyncLite, FBI, SBD, orbit motion detector, etc.
- generic damper studies
- TEL studies (not only Beam-Beam Compensation)
- Tevatron lattice modification studies

3. Plan for shutdowns

2 week shutdown (June)	Open aperture at F0 (new BPMs) Vacuum work (fix leaks, ferrite) Install new Tev bus transducer Alignment work (various) Replace electron gun in TEL Run cables for new C0 magnets Maintenance work (various)
5 week shutdown (November?)	Open aperture at C0 (new magnets) Alignment work Vacuum work Modify TEL magnetic system Maintenance work (various)